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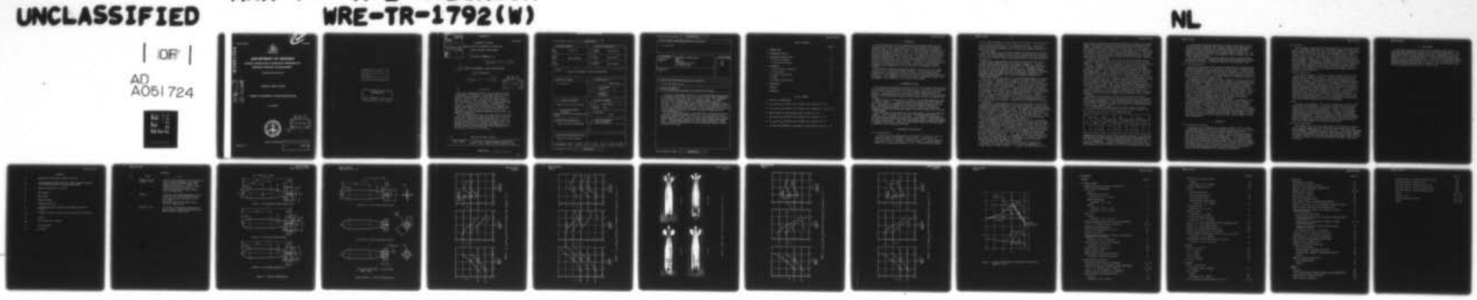

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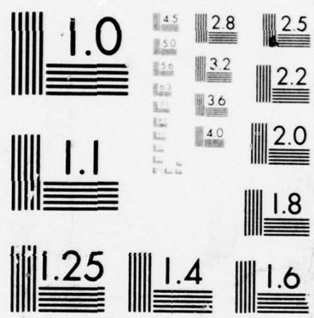

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STABILITY ENHANCEMENT OF BOMB CONFIGURATIONS

M.L. ROBINSON

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SUMMARY

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Oil flow studies showed that a successful means of alleviating fin-root separation on boattailed shapes was the use of a cylindrical or flared afterbody between the fins. Two tail units using these devices to achieve maximum efficiency were designed and tested in the transonic Mach number range. The performance of these tails was highly satisfactory in that canister stability requirements were closely approached without recourse to excessive fin span.

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The static longitudinal stability of fin-stabilized bomb configurations was examined in wind tunnel tests with a view to improving the performance of the stabilizing tail of a specific canister design. The study has indicated that an important factor in achieving maximum lift from a radial-fin tail of fixed span is the avoidance of flow separation at the fin roots. At transonic Mach numbers, traditional tail designs consisting of radial fins mounted on a boattail are prone to flow separation at the fin roots for practical tail-cone angles. Lift efficiency of the tail unit is then impaired, resulting in reduced longitudinal stability for the complete configuration.

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1. INTRODUCTION

The stabilizing tail of a bomb configuration must provide sufficient lift such that a satisfactory static margin is achieved throughout the operating incidence range. The traditional design of a stabilizing tail consisting of radial fins mounted on a boattail is prone to suffer from flow separation at the fin roots thus impairing lift efficiency. To achieve stability, the designer may then be obliged to increase the tail span or to adjust the centre of gravity forward by adding ballast to the vehicle nose. Obviously such solutions are inherently unsatisfactory, and also their implementation may not be possible because of operating constraints which impose a limit on fin span and restrict the centre of gravity to a specified range. Therefore, it is important that the maximum lift be obtained from a tail of given size, and to achieve optimum performance, flow separation at the fin roots must be suppressed as far as possible.

The problem of inadequate longitudinal stability arose in the early design phase of a W.R.E. canister development programme. The difficulty was later compounded by a requirement to reduce the fin span to the minimum possible dimension such that compatibility of the canister with existing bomb racks would be assured. The aerodynamic investigation which was undertaken to improve the performance of the stabilizing tail is given in this paper.

2. EXPERIMENTAL DETAILS

All the tests were carried out in the 0.36 m by 0.38 m slotted working section of wind tunnel S1 at the Aerospace Division of W.R.E. The tunnel is a continuous-flow facility with provision for close control of Mach number and stagnation pressure. The models which were 52.45 mm in diameter were mounted on a five component balance measuring side force, normal force, rolling, pitching and yawing moments. An incidence-roll mechanism provided remote control of pitch and roll attitudes.

Geometric details of the canisters on which the wind tunnel models were based are given in figure 1. A transition band comprising two rows of 0.12 mm diameter glass spheres was attached to the nose of each model 20 mm from the nose tip. Sublimation tests showed that the transition band was effective in promoting a turbulent boundary layer on the body at angles of incidence not exceeding about 20° for the Reynolds number of the tests, namely 3.4×10^5 based on body diameter.

The sting diameter at the model base was 0.23D where D is the model reference diameter. This corresponds to 65 per cent of the minimum base diameter of 0.35D pertaining to the Mk 3 and 4 canisters. The slightly tapering shank of the sting extended a minimum distance of 1.4D behind the base of the model before entering a sting shield. A small but undetermined degree of support interference is expected in the results, particularly for the Mk 4 series of canisters where a relatively bluff sting shield was used.

3. AERODYNAMIC INVESTIGATION

3.1 Force measurement

A definitive early configuration known as the Mk 3 canister is shown in figure 1(a) where all dimensions are in calibres. The canister is relatively short with a length to diameter ratio of 5.74, and the fin span varies from 1.50 to 1.62 calibre. The fin section is a modified double wedge and the leading edge sweepback is 30°. The specification required

a static margin $|\partial C_m/\partial C_N|$ at zero incidence of one calibre, with a centre of gravity position situated at 2.375 calibre from the nose. Therefore, to achieve the specified stability, the distance of the centre of pressure position from the nose should be not less than 3.375 calibre or 59 per cent of the body length.

Force and moment tests on the body without fins showed that the centre of pressure was located roughly 6 calibre ahead of the nose at zero incidence. The short nose (length 0.94 calibre) with its forward centre of pressure and the aft location of the boattail were responsible for this large destabilizing effect.

Normal force, pitching moment and centre of pressure data for the Mk 3 canister at Mach numbers 0.6 and 0.9 are shown in figure 2. At zero incidence the centre of pressure was located 3.1 calibre from the nose at $M = 0.6$, and 3.0 calibre from the nose at $M = 0.9$. Therefore, the Mk 3 tail failed to meet the stability specification by a substantial margin. Further, at incidence angles in excess of about 13^o, the slope of the pitching moment versus incidence curve fell away markedly, leading to an undesirable forward movement of the centre of pressure position and a reduced static margin.

Because the 1.62 calibre span tail created mounting problems on standard aircraft racks, an investigation was made with a greatly reduced tail span of 1.34 calibre. Although it was recognised that such a tail could not provide adequate stability with four fins, it was hoped that additional fins could be added to boost the performance. The Mk 4/4 canister with a four-fin tail unit is shown in figure 1(d), where the body shape is unchanged from the Mk 3 unit in figure 1(a). The fins of the Mk 4/4 tail incorporate a single-wedge section with a leading edge included angle of 14^o and a blunt trailing edge. The leading edge is swept back at 45^o in an attempt to achieve a rearward centre of pressure position of the tail. Signs of potential trouble were first observed in oil flow patterns which showed fin root separation at low incidence. The separation increased markedly in extent on the upper (low pressure) surfaces of the lifting fins as incidence was increased.

Normal force, pitching moment and centre of pressure data for the Mk 4/4 configuration at a Mach number of 0.9 are shown in figure 3. The low pitching moment throughout the incidence range and resultant unsatisfactory centre of pressure position are clearly evident. The addition of four interdigitated fins to form the Mk 4/8 configuration shown in figure 1(e) improved the stability slightly at low incidence, but in the range above about 14^o incidence, the stability was degraded significantly by the additional fins. Thus any gains due to increased lifting area were negated by fin interference effects and increased flow separations at the fin roots.

Close examination of oil flow patterns obtained on the Mk 4/4 configuration at an incidence of 8^o revealed that on the low pressure surface of each lifting fin a separation line extended from about the 25 per cent root chord position to the trailing edge at an angle of about 7^o to 8^o to the axis of symmetry of the canister. To eliminate or at least attenuate the separation it was decided to insert a 7.5^o semi-angle flare between the fin roots such that the intersection of the flare with the fin surfaces followed roughly the observed separation line at $\alpha = 8^o$. This configuration designated Mk 4/8F is shown in figure 1(f). A precedent for this type of modification was noted in the M823 research store programme(ref.1,2) where a relatively small change in afterbody shape to relieve adverse pressure gradients produced a significant improvement in stability.

The addition of the flare to the Mk 4/8 canister was successful in significantly improving the stability of the canister throughout the incidence range as shown in figure 3. It seems, therefore, that the flare

was effective in suppressing separation throughout the transonic Mach number range since the centre of pressure position was almost independent of Mach number. Although the stability of the Mk 4/8F canister was well below specification with a static margin of 0.4 calibre only, this configuration was equally as successful as the best of a large number of 1.34 calibre span tail designs which were examined in the present investigation. Variations in fin chord, leading edge sweep, afterbody geometry and a number of minor modifications such as slotted fins were tested without materially improving on the Mk 4/8F configuration.

Consequent on the findings of this phase of the investigation, it was considered expedient to relax the fin span constraint to achieve adequate stability. Bearing in mind the compatibility of the canister with existing bomb racks, a minimum fin span consistent with stability was paramount.

Stability calculations showed that a fin span of 1.55 calibre could provide the necessary static margin throughout the subsonic and transonic Mach number ranges. It was shown that a canister with this fin span could be accommodated on standard bomb racks by using packing pieces. Two configurations were designed to conform to the 1.55 calibre span limitation, and these are shown in figure 1(b) and (c). The Mk 5 design uses a 7° semi-angle flare between the fins to suppress separation, whereas the Mk 6 design uses a cylindrical body 0.525 calibre in diameter for the same purpose. To avoid fouling the bomb racks, the fins are cropped towards the rear. The fin section is a single-wedge with a leading edge included angle of 5° and a blunt trailing edge. The sweep-back angle of the leading edge is 30°.

Oil flow patterns obtained on the Mk 6 canister at a Mach number of 0.8 are shown in figure 4. In the range of incidence shown, there is no obvious evidence of axial flow separation in the fin root region, although the flow over the fins becomes markedly three-dimensional with increasing incidence.

Aerodynamic data obtained on the Mk 5 and 6 canisters are shown in figures 5 and 6, and the general levels of normal force and pitching moment show a marked improvement over the corresponding data of figures 2 and 3. Each configuration exhibits a highly satisfactory restoring pitching moment characteristic, indicating that the stabilizing tail is lifting efficiently in the incidence range 0° to 20°.

It is informative to compare the zero-incidence centre of pressure position and static margin $|\partial C_m/\partial C_N|$ of the Mk 3, 5 and 6 canisters, and the relevant data are given in the accompanying table.

M \ Conf'n.	Mk 3		Mk 5		Mk 6	
	X_{cp}	$\lvert\partial C_m/\partial C_N\rvert$	X_{cp}	$\lvert\partial C_m/\partial C_N\rvert$	X_{cp}	$\lvert\partial C_m/\partial C_N\rvert$
0.6	3.10	0.72	3.28	0.90	3.31	0.93
0.9	3.00	0.62	3.27	0.89	3.25	0.87

Remembering that the tail span of the Mk 5 and 6 canisters is less than the maximum span of the Mk 3 canister, the improvement in static margin of the Mk 5 and 6 designs over the Mk 3 configuration of more than 40 per cent at M = 0.9 is noteworthy. A further point of interest is that the static margin of the Mk 5 and 6 canisters is degraded less by the increase in the Mach number from 0.6 to 0.9 than is the case of the boattailed Mk 3 design.

In terms of the originally specified one calibre static margin at zero incidence neither of the Mk 5 and 6 canister designs, each with a nominal 0.9 calibre static margin at zero incidence, fulfilled the requirement. However, the centre of pressure position moved rearward rapidly with increasing incidence such that at all incidence angles in excess of 5^{o}, the centre of pressure position was located greater than one calibre aft of the centre of gravity location.

From the static stability viewpoint there was little to choose between the Mk 5 and 6 designs. However, the Mk 6 design was preferred for further development for reasons of structural simplicity and reduced base drag.

3.2 Pressure measurement

To verify the hypothesis that a region of favourable pressure gradient is produced by replacing the rear segment of a boattail with a cylindrical body, a limited programme of pressure measurement was undertaken. Three surface pressure holes were located on the cylindrical afterbody section of a finless version of the Mk 6 canister. Surface pressures were measured relative to tunnel static pressure by a 34 kPa range differential transducer incorporated in a Scanivalve pressure scanning system.

Experimental data so obtained are shown in figure 7, and the existence of a favourable pressure gradient over the full length of the cylindrical afterbody is confirmed. However, inviscid flow calculations by Haselgrove(ref.3) have shown that the cylindrical afterbody produces a region of increasing adverse pressure gradient on the boattail ahead of the boattail-cylinder junction. Computed pressure distributions are included in figure 7 where it is seen that the adverse gradient on the boattail-cylinder terminates at an axial position corresponding to 30 per cent of the fin root chord. Nevertheless, the dominant feature of the relevant pressure distributions in figure 7 is the net favourable gradient over the length of afterbody corresponding to the location of the fin root chord.

Since the pressure distribution due to added fins is superimposed on the already existing distribution on the afterbody, the severity of adverse pressure gradients over the rearmost 70 per cent of the upper surfaces of the lifting fins is reduced in the fin root region by the pre-existing favourable gradient. Therefore, the boundary layer in the vicinity of the fin roots is less likely to separate than would be the case for an unmodified boattail with its associated adverse pressure gradient throughout its length. The modified boattail arrangement should therefore support higher fin loadings and give increased lift, an observation which is well supported by the force measurements.

4. DISCUSSION

4.1 Alleviation of separation

Aerodynamic force and moment data obtained on the Mk 5 and 6 canisters have demonstrated the efficacy of the present technique of using a correctly proportioned cylindrical or flared afterbody between radial fins to alleviate flow separation at the fin roots. Results of pressure measurements have shown that the modified afterbody creates favourable aerodynamic interference between the fin and centrebody flows. It is reasoned that this favourable interference reduces the magnitude of the adverse pressure gradient on the inboard upper surfaces of the lifting fins and thus renders the boundary layer in the vicinity of the fin roots less prone to separation. The improved static stability of the Mk 5 and 6 canisters over that of the Mk 3 design highlights the importance of attached flow in the fin root region such that satisfactory lift loadings are maintained.

4.2 Scale effect

A brief comment is warranted on the applicability of the present findings to full scale flight conditions where the Reynolds number is typically an order of magnitude greater than that of the wind tunnel tests. Reasonable care was taken in the tests to ensure the development of a turbulent boundary layer on the body downstream of the transition band. Provided that the boundary layer is fully developed, the essential features of the layer including susceptibility to separation are relatively insensitive to Reynolds number. Furthermore, in attached flow the pressure distributions on the afterbodies are independent of Reynolds number to a first order since the displacement thickness is only weakly dependent on Reynolds number. Therefore, the findings made on the basis of the wind tunnel results are expected to be equally valid for the higher Reynolds numbers which are typical of flight conditions.

4.3 Support interference

Every effort was made to ensure that support interference in the wind tunnel tests was minimal (Section 2). Oil flow studies on the Mk 4/4 canister showed no evidence of separation directly attributable to the sting or its support. Nevertheless, the oil flow and force measurements have shown that the boundary layer on the afterbodies of the Mk 3, 4/4 and 4/8 canisters is subject to separation at the roots of the lifting fins. Unfavourable support interference would tend to exacerbate this condition, further degrading the lifting performance of the tail. It is therefore possible that the wind tunnel results on the Mk 3 and 4 configurations are unduly pessimistic in terms of longitudinal stability and that the performance gains achieved by the use of the cylindrical and flared afterbodies are then unduly optimistic. There is no question, however, that incipient separation conditions should be avoided, and so design modifications which promote attached flow are to be recommended.

4.4 Drag

No comparative measurements of the drag increment due to the afterbody modifications have been made. On an inviscid flow basis the base area increase over that of the standard boattail results in increased form drag because of the base drag contribution. However, if the afterbody simply replaces a region of separated flow, no increase in drag should result and possibly a reduction in drag may be achieved by a correctly proportioned afterbody. The drag increment due to the afterbody whether positive or negative is probably insignificant in terms of the total drag which is primarily due to skin friction at subsonic speeds and to form drag in the high transonic and supersonic speed ranges.

4.5 Practical application

Large numbers of stores stabilized by radial fins attached to boattails are in existence today, and it is likely that some designs suffer from varying degrees of flow separation at the fin roots. Under these conditions, static stability is degraded and dynamic stability may be adversely affected. In lieu of redesigning the tail unit of a deficient store, a simple modification would be the use of a correctly proportioned afterbody between the fins or fin root fairings to correct the flow problem and improve longitudinal stability.

5. CONCLUSIONS

A wind tunnel investigation of the static longitudinal stability of fin-stabilized bomb configurations has been made at transonic Mach numbers. The study revealed that fin-root separation was largely responsible for the poor performance of early designs of stabilizing tails incorporating radial fins mounted on a 7° 40' semi-angle boattail. A successful means of suppressing fin-root separation on boattailed shapes was the use of a cylindrical or flared afterbody inserted between the fins. Two tail units using these separation-suppression devices performed well, and canister stability requirements were closely approached without the use of excessive span.

NOTATION

C_N	normal force coefficient, (normal force)/QS
C_m	pitching moment coefficient about centre of gravity position 2.375 calibre from nose, (pitching moment)/QSD
C_p	pressure coefficient $(p - p_{st})/Q$
D	body diameter
M	Mach number
Q	dynamic pressure
S	reference area $\pi D^2/4$
X_a	distance downstream from boattail/afterbody junction in calibres
X_{cp}	distance of centre of pressure position from nose in calibres
p	pressure
p_{st}	free-stream static pressure
α	incidence angle
ϕ	roll angle

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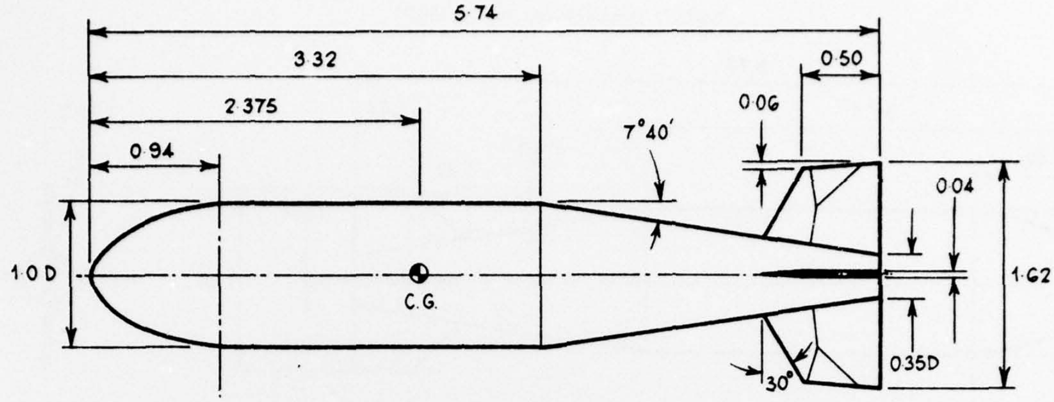
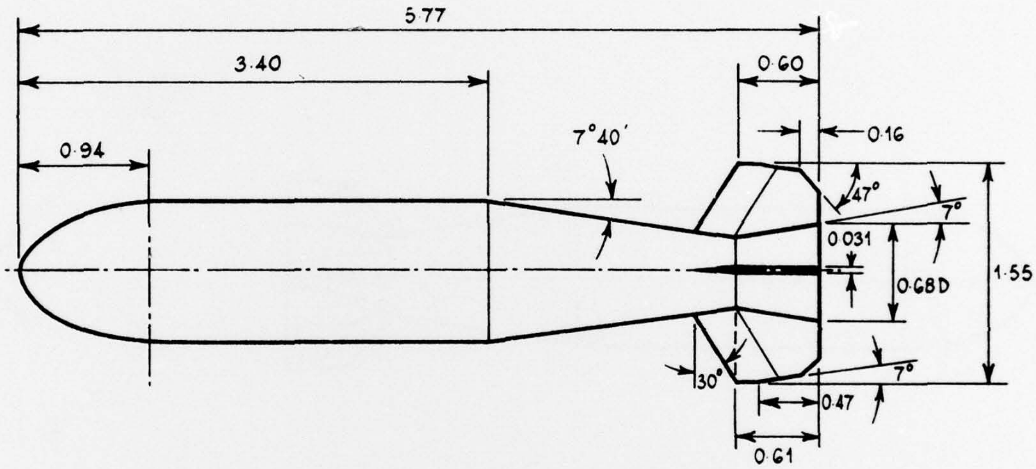
3	Haselgrove, M.K.	"Calculation of Pressure Distributions on Two Axisymmetric Boattailed Configurations". WRE-TR-1779(W), February 1977.

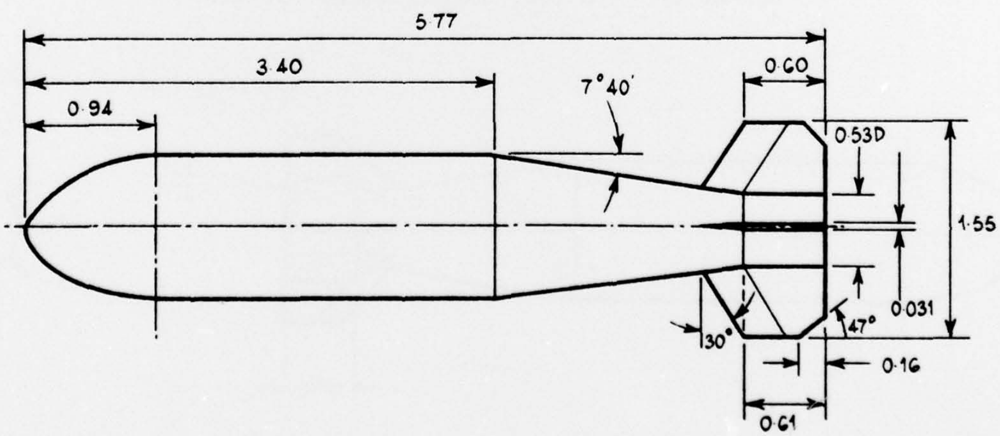
NOTE: DIMENSIONS IN CALIBRES



(a) Mk 3 - 4 fins-modified double wedge section

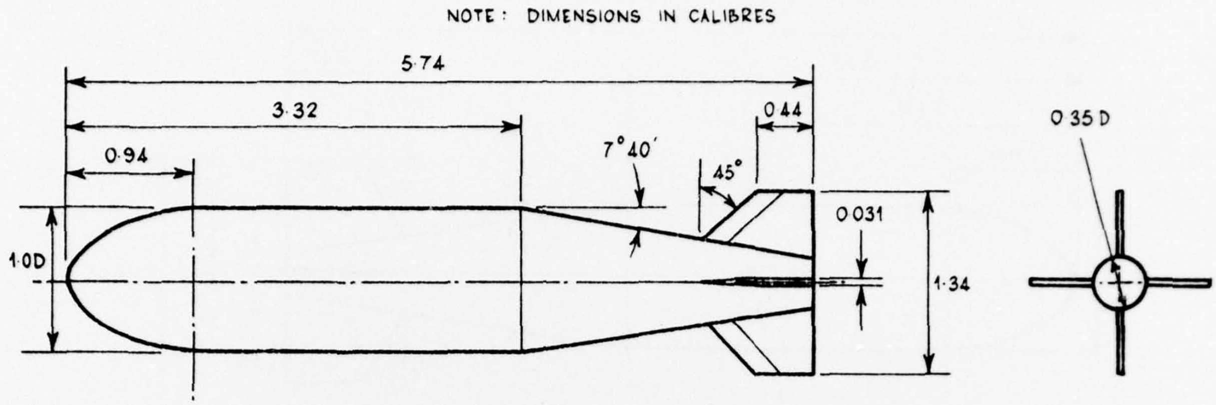


(b) Mk 5 - 4 fins-single wedge section

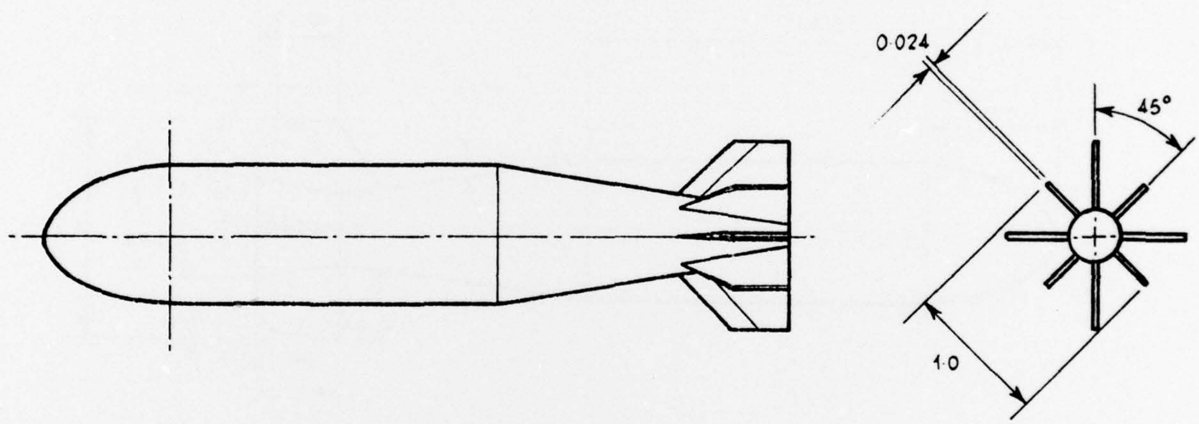


(c) Mk 6 - 4 fins-single wedge section

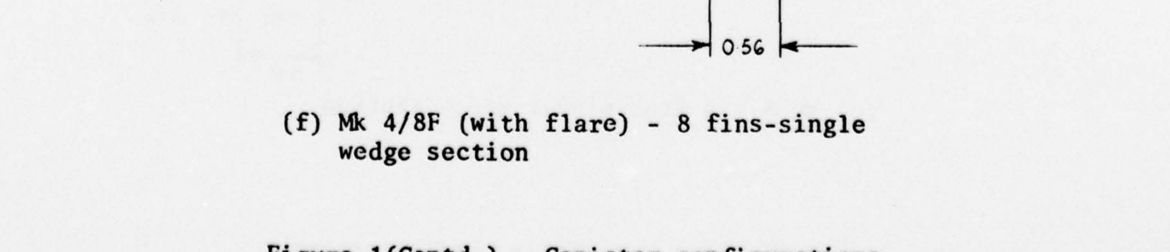
Figure 1. Canister configurations



(d) Mk 4/4 - 4 fins-single wedge section



(e) Mk 4/8 - 8 fins-single wedge section



(f) Mk 4/8F (with flare) - 8 fins-single wedge section

Figure 1(Contd.). Canister configurations

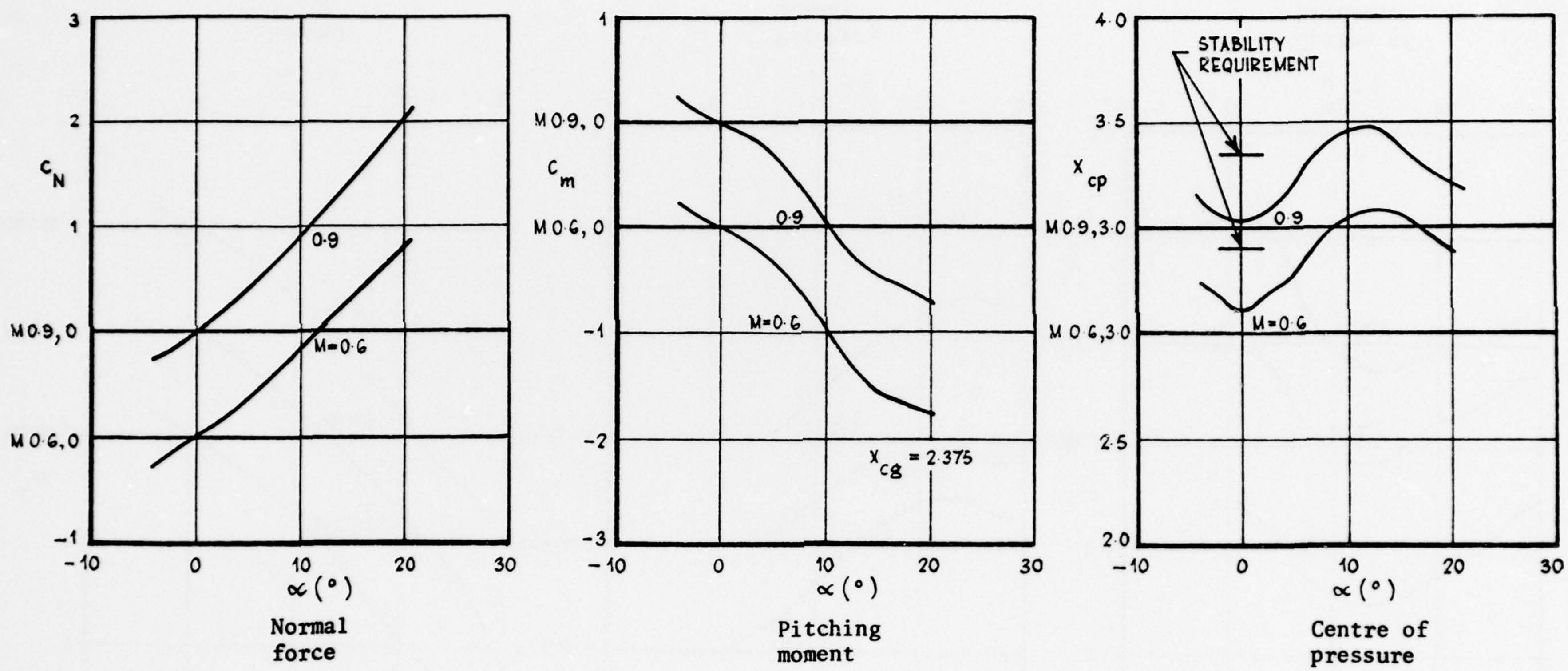


Figure 2. C_N, C_m and X_{cp} variation with incidence, Mk 3 canister, $\phi = 0^o$

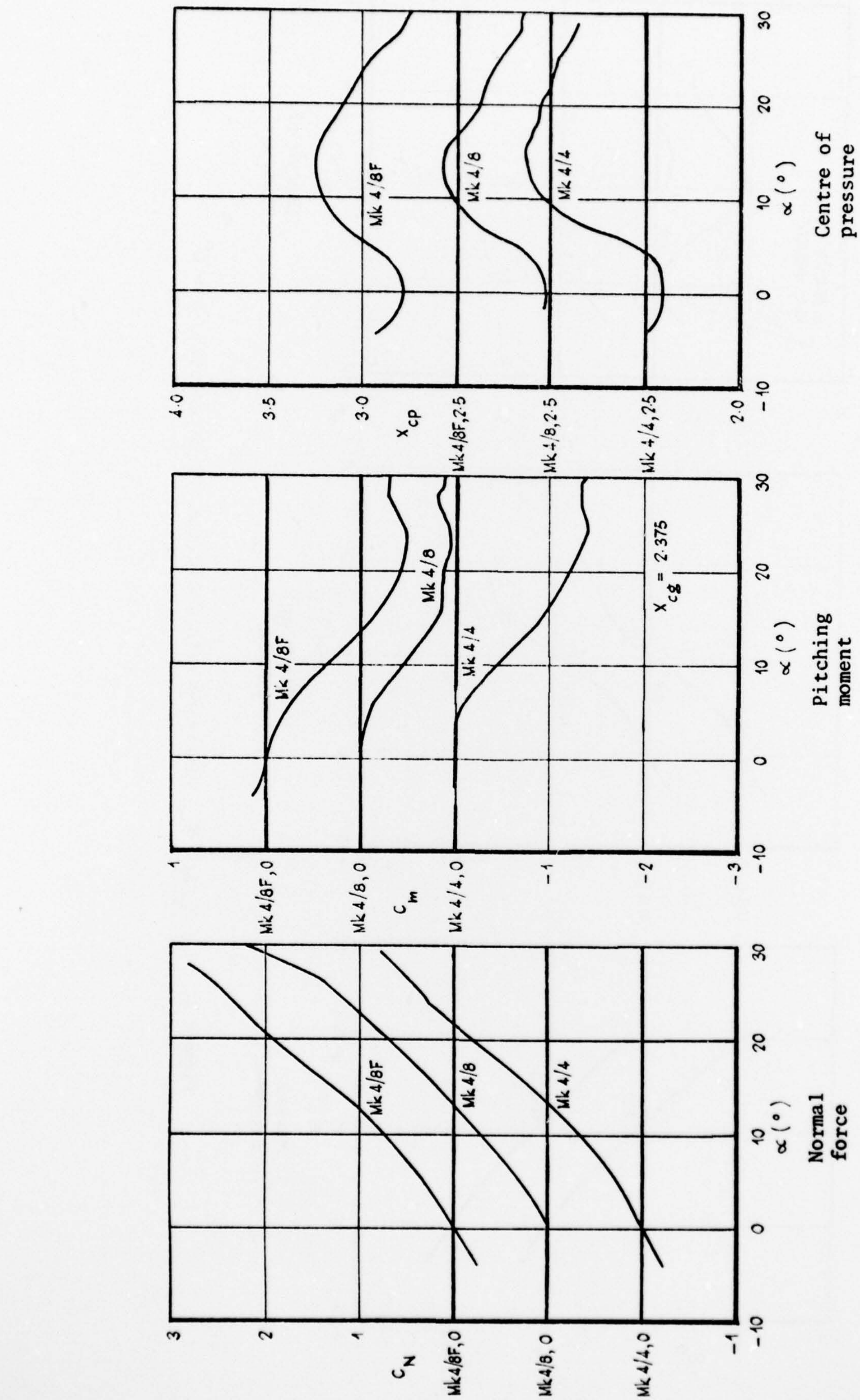


Figure 3. C_N, C_m and X_{cp} variation with incidence, Mk 4 canister, M = 0.9, $\phi = 0^o$

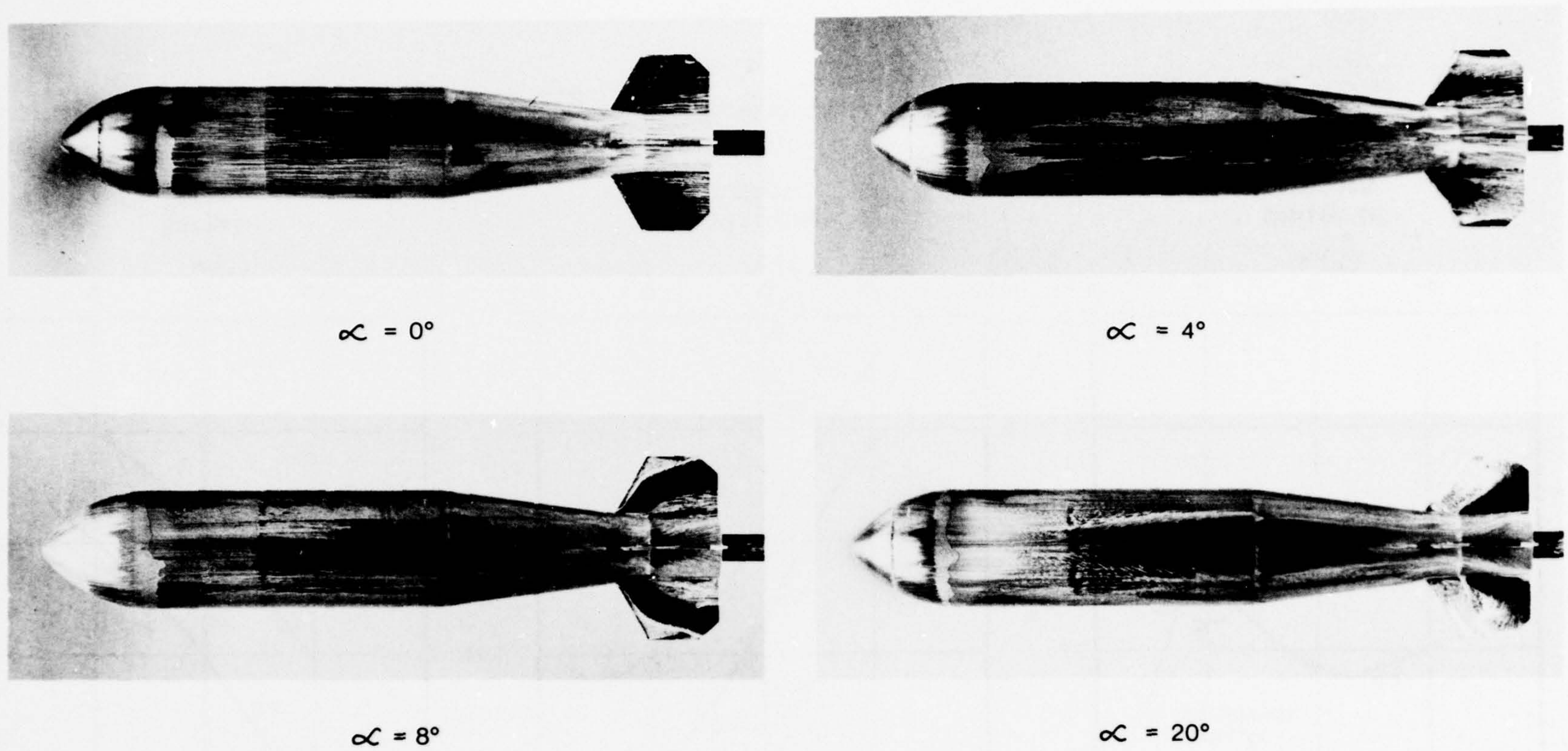


Figure 4. Upper surface oil flow patterns, Mk 6 canister, M = 0.8

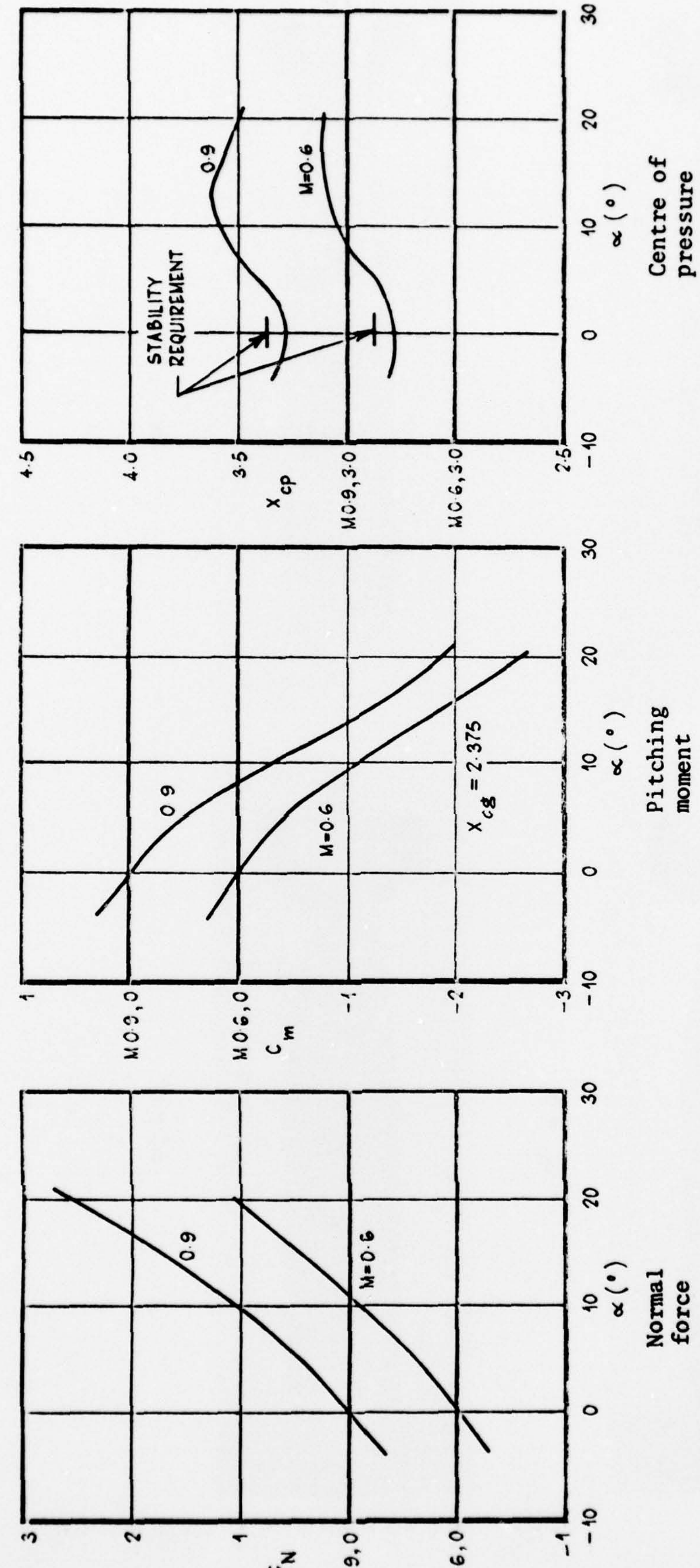


Figure 5. C_N, C_m and X_{cp} variation with incidence, Mk 5 canister, $\phi = 0^o$

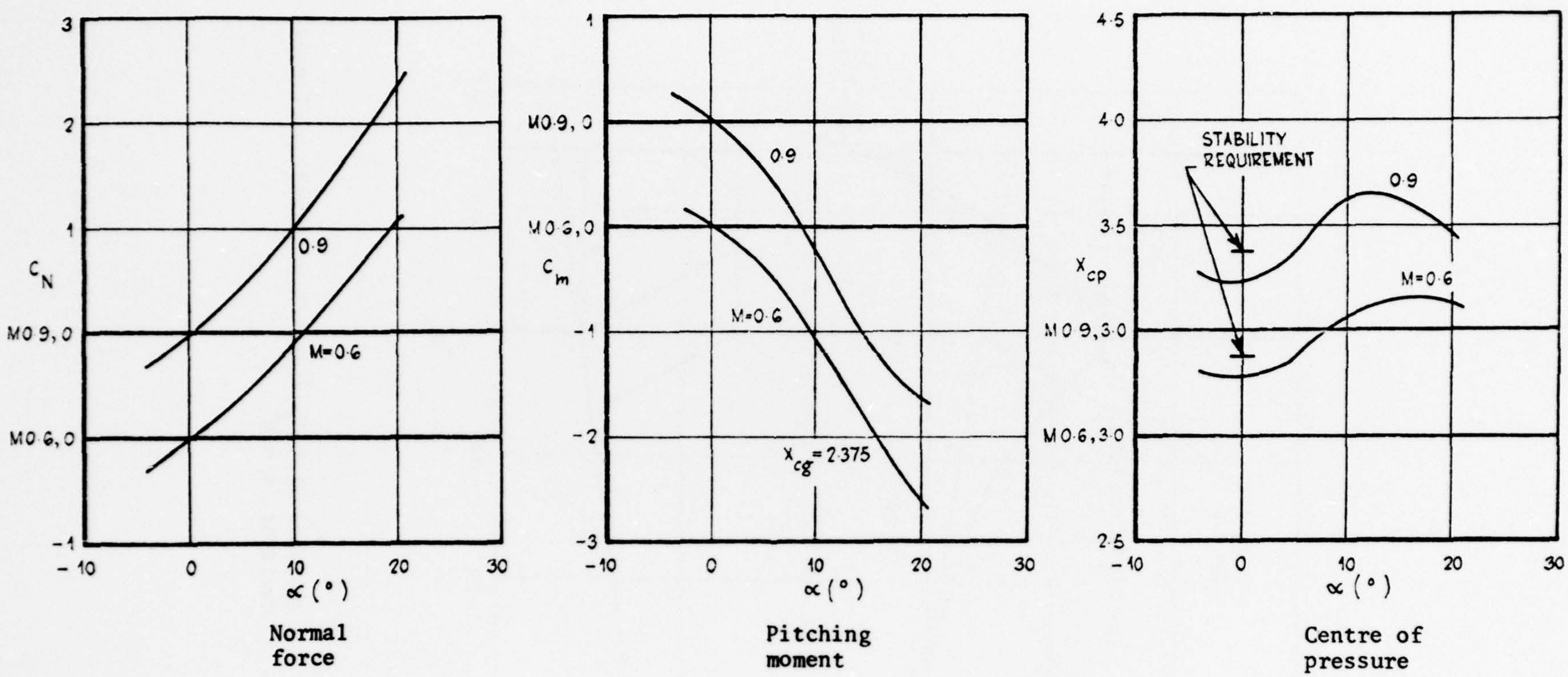


Figure 6. C_N, C_m and X_{cp} variation with incidence, Mk 6 canister, $\phi = 0^o$

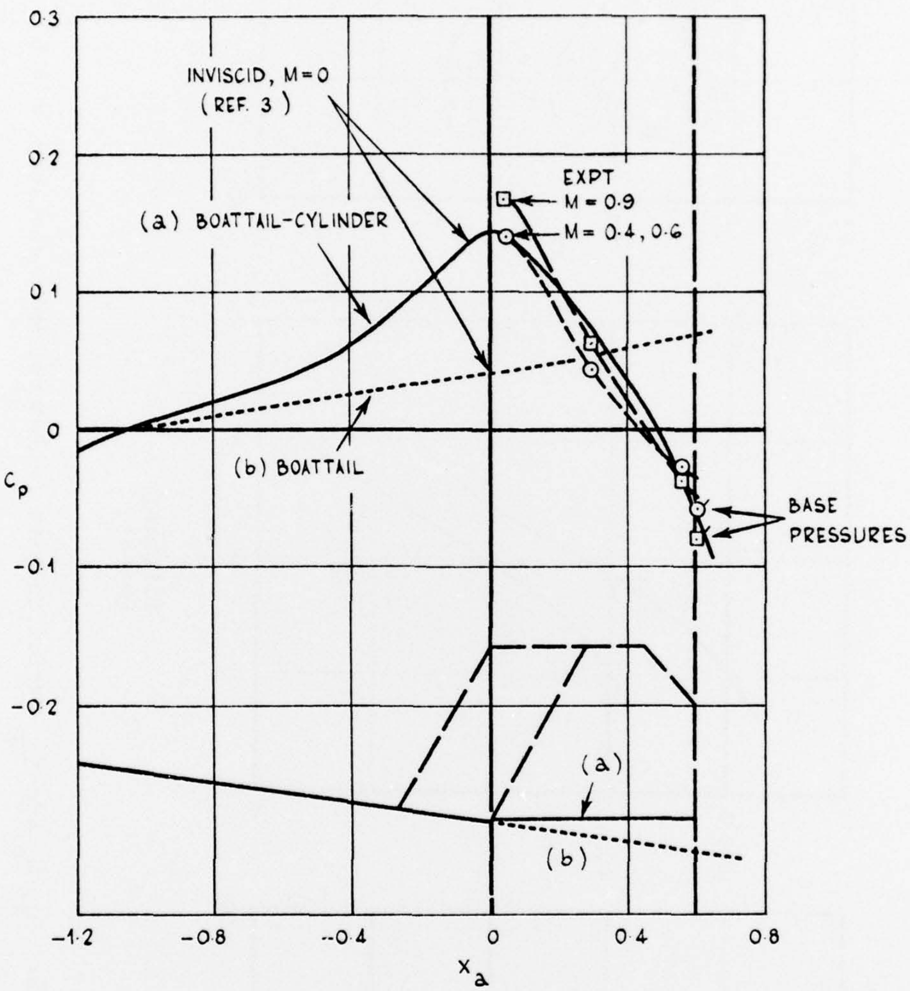


Figure 7. Pressure distributions on afterbody of finless Mk 6 canister, $a = 0^{\circ}$

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